SOME CHARACTERISTICS OF TEXAS RAINFALL.

By I. R. Tannehill, Meteorologist.

[Weather Bureau Office, Galveston, Tex., June 14, 1923.]

The most convenient measure of monthly and annual intensities of precipitation is the average amount on days with 0.01 inch or more, obtained by dividing the total amount by the number of days with precipitation in measurable amounts. Such values, indicating the annual march of rain intensity at Galveston, Tex., as an average for the years 1908 to 1922, inclusive, are shown in Figure 1.

There are two rather pronounced maxima—one in May, the other in October. The minimum in July and the relatively low intensity in August are remarkable in view of the high vapor content of the atmosphere at that season. To demonstrate that this is not purely fortuitous, similar curves are shown in Figure 2, for the 15-year periods 1878 to 1892, inclusive, and 1893 to 1907, inclusive. In the curves of Figure 2, both early maxima occur in June while the autumn maxima occur in September in one average and in October in the other. The minimum occurs in July in one average and in August in the other.

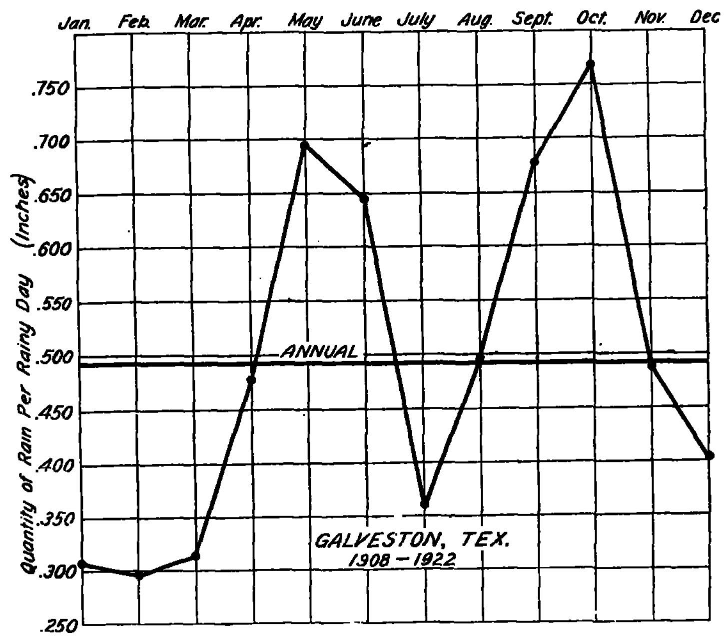

Fig. 1.—Monthly mean quantity of rain per rainy day at Galveston, Tex.

These curves indicate that the intensity of rainfall at Galveston is extraordinarily low in midsummer.

Since these curves are based upon the average quantity of rain on a rainy day, a further calculation of rain intensity has been made to determine the reliability of this measure of rain intensity.

The Weather Bureau tabulates for each month the maximum fall of rain for a five-minute period in that month. Averages of these maximum five-minute intensities for the period 1908 to 1922, inclusive, have been calculated. These are shown in Figure 3. As a further test, the number of hours during which rain fell in each month for the period 1908 to 1922, inclusive, has been determined. This is taken as the duration of rainfall for each month. The monthly rainfall amount divided by this value of duration in hours, gives a value of rain intensity per rainy hour. The resultant values are shown in Figure 3 as the average monthly rain intensity. These curves show roughly the same annual variation, with a minimum in July.

There are undoubtedly many factors influencing the intensity of rainfall. It is obvious, however, that, other factors remaining constant, the intensity of rainfall will vary directly with the temperature, which determines the maximum vapor content of the atmosphere.

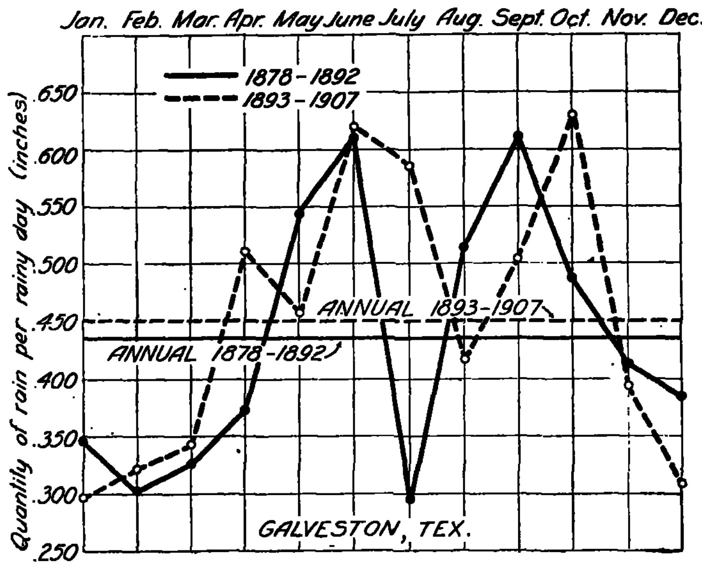

Fig. 2.—Quantity of rain per rainy day at Galveston, Tex., as shown by two 15-year periods.

To illustrate this point, see Figure 4, which shows the annual march of temperature and rain intensity at Chicago for the years 1871 to 1910, the intensities being expressed as average rainfall per rainy day.[1]

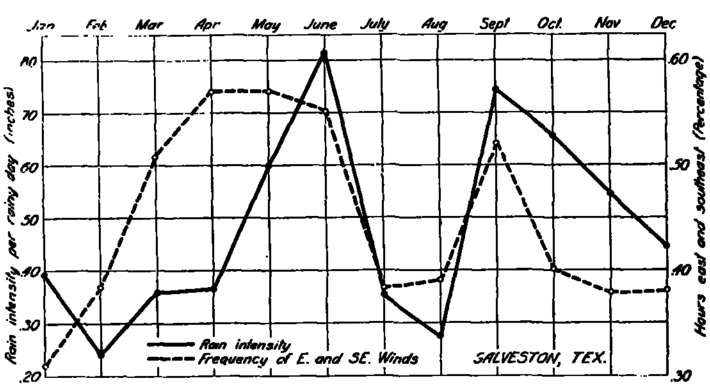

Fig. 3.—Monthly mean maximum rainfall for a 5-minute period at Galveston, Tex.

Here the intensity varies rather uniformly with the temperature, the maximum intensity occurring in July. This is in marked contrast to the distribution of intensity at Galveston. The mean annual intensity at Chicago is 0.27 inch; at Galveston, for the 45-year period, 1878 to 1922, it is 0.46 inch, nearly double that of Chicago. Yet, the mean intensity at Chicago in July is 0.37 inch and at Galveston 0.41 inch. Galveston is only slightly in excess of Chicago in July intensity. On the other hand, in June Chicago averages 0.32 inch, Galveston 0.62 inch; in October Chicago is 0.26 inch, Galveston 0.63 inch.

[1] Cox and Armington: *Weather and Climate of Chicago.*

The distributions at the two stations are strikingly dissimilar, and, while Chicago is evidently affected largely by variations in temperature and consequently in vapor content, the rain intensity at Galveston is evidently controlled by some other pronounced influence, which affects the distribution of moisture over the State and its availability as rainfall.

The distribution of rainfall intensity, characteristic of Galveston, is reflected in the rainfall curves for a considerable portion of the State of Texas and adjoining sections. A number of these diagrams are shown in Figure 5. These curves are based upon station annual summaries, and while the period of observation varies with the station, the tendency toward a maximum rainfall in May to June and again in September, with a secondary minimum in July or August, is quite apparent, thus indicating the influence of increased rain intensity at those periods in spring or early summer and in the autumn. It is true that the quantity of rain is the product of frequency by intensity, but these increased rainfall yields are due to intensity and not to frequency, as an examination of records of number of rainy days will indicate. In Table 1, the frequency of rainy days at Galveston, 1878 to 1922, inclusive, is shown. Though the June rainfall exceeds that of July, the number of rainy days in July is considerably in excess of that in June.

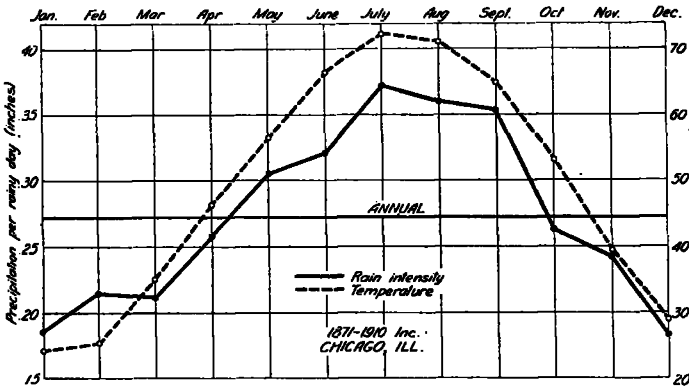

FIG. 4.—Annual march of temperature and rain intensity at Chicago, Ill.

The Gulf of Mexico is undoubtedly the chief source of moisture for this region. The frequency, velocity, and direction of the moisture-bearing winds determine the characteristics of its rainfall.

TABLE 1.—*Average number of days with 0.01 or more precipitation at Galveston, Tex., period 1878 to 1922, inclusive.*

January	10.2
February	9.2
March	8.1
April	6.7
May	6.2
June	6.9
July	9.0
August	9.5
September	9.3
October	7.0
November	7.8
December	9.8

The annual variation in frequency of east and southeast winds at Galveston, Tex., is shown in Figure 6. The percentage of total hours each month in which the wind blew from east and southeast, for the five years, 1918 to 1922, inclusive, are shown, together with the average rain intensities for the same period.

It will be evident from a study of this figure that there is a well-defined relationship between frequency of these winds and the intensity of rainfall, bearing in mind, however, that temperature also affects rainfall intensity. The prevailing southeasterly wind over Texas is in the nature of a monsoon, and its advance and retreat in May to June and September to October, respectively, are attended by increased intensity of rainfall, undoubtedly because of the attendant shift in wind direction.

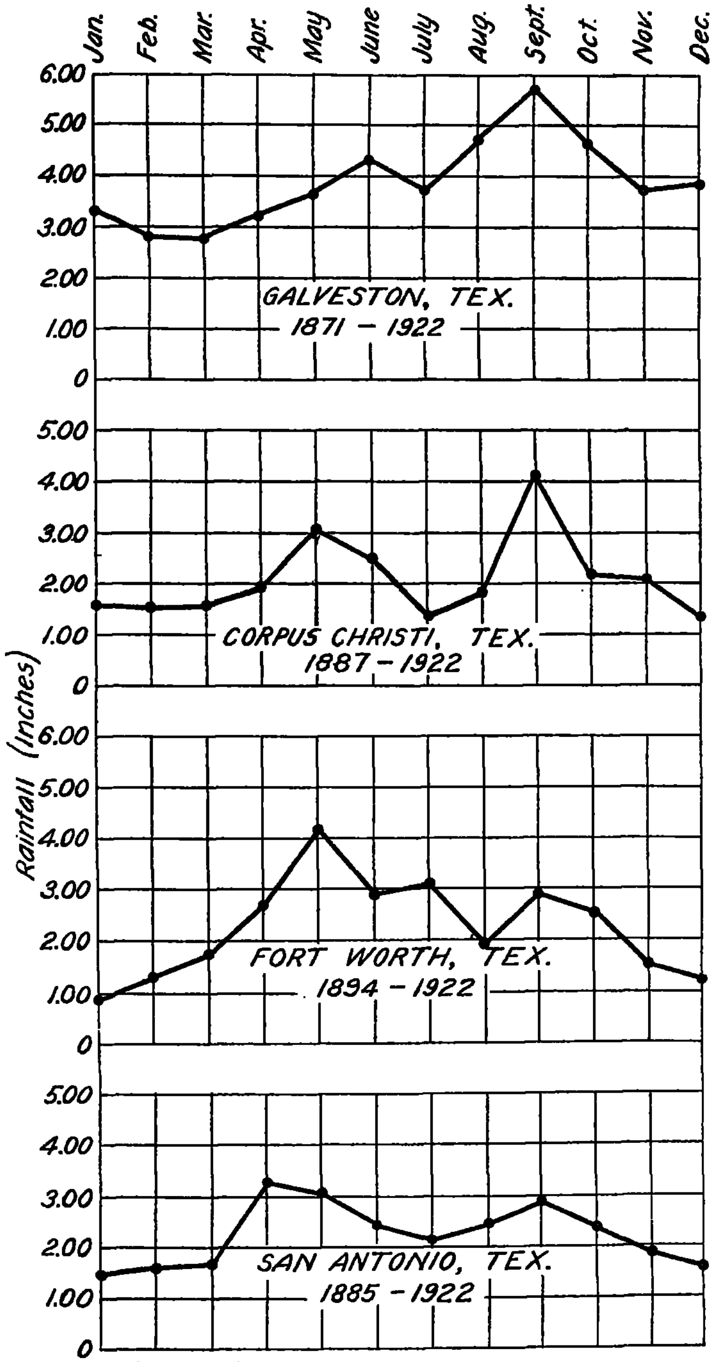

FIG. 5.—Annual distribution of rainfall intensity at various Texas stations.

This backing of the wind to easterly in the late spring and early fall, extends to considerable heights above the earth's surface.

Table 2 shows the average wind directions and humidity percentages at 1,000 meters over Groesbeck, Tex., during the period October, 1918, to December, 1920. Note that the movement has a westerly component in all months except June and September, when it shifts to easterly.[2]

[2] Gregg, Willis R.: An Aerological Survey of the United States. MO. WEATHER REV. SUPPLEMENT No. 20.

TABLE 2.—*Based on 670 observations at Groesbeck, Tex., at altitude of 1,000 meters, October, 1918, to December, 1920, station altitude 141 meters.*

WIND DIRECTION AT 1,000 METERS AT GROESBECK, TEX.:

January	N. 65 W.
February	S. 79 W.
March	S. 26 W.
April	S. 28 W.
May	S. 23 W.
June	S. 14 E.
July	S. 32 W.
August	S. 28 W.
September	S. 4 E.
October	S. 5 W.
November	S. 71 W.
December	S. 50 W.

RELATIVE HUMIDITY, PER CENT, AT 1,000 METERS AT GROESBECK:

January	65
February	60
March	53
April	59
May	72
June	69
July	68
August	74
September	71
October	78
November	61
December	54

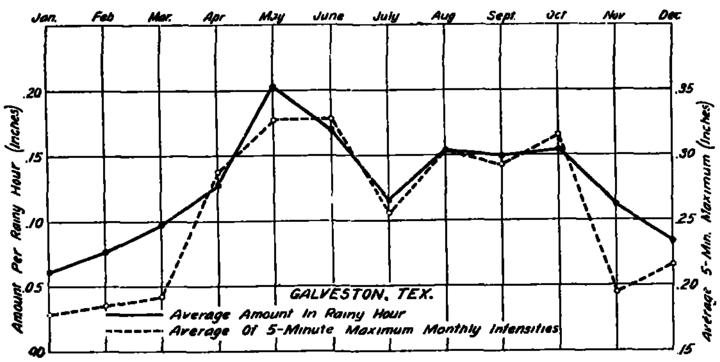

FIG. 6.—Annual variation in frequency of east and southeast winds at Galveston, Tex.

These upper-air observations cover too short a period to establish reliable means, yet they are sufficient to indicate that this shift of wind direction in midsummer, coincident with the reduction in rain intensity, extends well above the surface. It is interesting to note low relative humidity in July and high values in May and October.

The prevailing southeasterly wind over the Texas coast is due to temperature differences between land and water.[3]

Again referring to Figure 6, we note that the frequency of east and southeast winds is at a maximum in April to May, at which time the mean temperature rises above 70° at Galveston. It diminishes rapidly in frequency in and after September, when the mean temperature falls below 75°. To maintain the circulation, a higher land temperature is necessary in the fall, because of heating of the water surface during the summer months. It will be noted from a study of the upper-air observations that the wind becomes south-southwest in midsummer at 1,000 meters, while at the surface the wind is apt to prevail from the south.

These shifts in direction of the monsoon-like wind are due to migration and expansion of the area of maximum heat in the interior. In midsummer the heated area extends northward and the monsoon veers to the south. Table 3 gives the mean temperature at Forth Worth and at San Antonio for the months May to October. The higher temperature in each month is *in italics*. It will be seen that in the months of May and June and again in September and October, San Antonio has a higher mean temperature than Forth Worth, indicating that the stronger temperature gradient lies toward the west, hence the strong easterly component in the wind movement.

In July and August, particularly the former, it is warmer at Fort Worth, indicating that the stronger gradient now lies to the northward giving rise to southerly winds at the surface. There is a south-southwest wind aloft with lower relative humidity. It appears that in midsummer the heated area has expanded, covering a vast area of the Middle West and Southwest, and that a gradient is established from the water surfaces of the Gulf and Pacific toward this vast heated interior. This is in contrast to the earlier and later terms during which the local area of heat in the Southwest establishes a temperature gradient toward the Gulf.

This midsummer southerly wind moves more slowly, due to less pronounced temperature gradients. Its slower movement is more favorable for convection and rainfall occurs with greater frequency, though with less intensity.[4]

TABLE 3.—*Mean temperatures.*

	May.	June.	July.	Aug.	Sept.	Oct.
Fort Worth (1894–1922)	73.2	80.1	*83.7*	*82.9*	76.7	66.3
San Antonio (1885–1922)	*74.8*	*80.4*	82.4	82.0	*77.1*	*69.2*

Table 1 shows that at Galveston the number of rainy days increases from 6 in May and 7 in June to 9 in July. The southerly wind, however, is drier and consequently yields less moisture, as is shown in Figure 5.

As the water temperature continues to rise, and the temperature gradient is consequently reduced in the autumn, the area of maximum heat again shifting to the southwest, we find a slow moving current with a pronounced easterly component in September, lingering into October, at which season the rainfall over southern Texas is at maximum frequency and intensity, as evidenced by the September rainfall at Corpus Christi, Brownsville, and San Antonio.

In conclusion, the movement of rain-bearing winds and resultant distribution of rainfall over Texas have the following characteristics:

(1) In spring a strong southeasterly wind blowing into the heated southwest from a relatively cool water surface; winds sufficiently strong at frequent intervals to suppress convection over the southern portion of the State; moisture content high and rainfall intense when it does occur.

(2) Slower wind movement more favorable for convection over the northern portion of the State; high vapor content and period of maximum rains in the north.

(3) Slower movement from south in midsummer, as air drains toward heated portion of north Texas and adjoining districts; increased rain frequency near the source of moisture but prevailing wind drier, yielding less intense rainfall.

(4) Southeasterly winds again setting in with autumn, blowing into area of maximum heat in southwest, but with higher water temperature and consequent slower

[3] McAuliffe, J. P.: Cause of the accelerated sea-breeze over Corpus Christi, Tex. MO. WEATHER REV., Nov., 1922, 50: 581-582.

[4] Tannehill, I. R.: Wind velocity and rain frequency on the South Texas Coast, MO. WEATHER REV., September, 1921, 49: 498-499.

wind movement favorable for greater rain frequency; high vapor content favorable for increased rain intensity. When these conditions occur, the record-breaking rains of southern Texas are sometimes recorded. This condition is favorable for the development and movement of cyclonic disturbances from east to west and intense rainfall results.

We find then that conditions favorable for rainfall distribution of certain characteristics become established over this region and persist for considerable periods. These conditions do not return each year at the same time; for example, the midsummer condition sets in earlier in some years than others; the spring and autumn conditions shift considerably from year to year.

The solution is found in the distribution of temperature over land and water surfaces. That any given condition has become established will be apparent from the wind movement at the surface and aloft. With the knowledge that such a condition has become established, the general characteristics of the rainfall over this region should then be forecast as regards frequency, quantity, and intensity. Further upper air observations, disclosing the structure of the atmosphere over this region for a number of years, thus giving more reliable data concerning prevailing winds aloft, average movements, etc., will undoubtedly assist.

PANAMA CLIMATE.[1]

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[Balboa Heights, Canal Zone, May 4, 1923.]

Panama lies wholly in the Torrid Zone and is very close to the thermal equator. Its climate may be characterized as warm, humid, and equable. The year is divided into a dry season of four months' duration, January to April, inclusive, and eight months' wet season.

The climate of Panama is approximately that of July in the North Atlantic States from Virginia to New Hampshire, except that during the rainy season it has more rain and humidity. The mornings are bright and fresh, the days warm, the evenings refreshing, and the nights gloriously clear; one sleeps under at least one sheet. In the high lands of the Province of Chiriqui temperatures run down to as low as 50° F. at night.

An American in Panama is often amused at his mail from the United States, written during a sweltering July or August with 95° to 105° F. temperature. His friend will write of the local torridity, the hot nights and their discomfort, and ends up with a sympathetic, "I do not see how you stand it down there."

Taking the month of July as the criterion for a warm month (and remembering that Panama's monthly average temperatures vary but slightly), the following table is a comparison for cities of the United States selected at random:

Stations.	Mean July temperature.	Record temperatures any month.		Mean annual relative humidity.	Mean annual rainfall.
		Highest.	Lowest.		
Mobile	80	102	−1	79	62.0
Denver	72	105	−29	52	14.0
Washington	77	106	−15	72	43.5
Key West	84	100	41	78	38.7
Chicago	72	103	−23	74	33.3
New York	74	100	−13	72	44.6
New Orleans	81	102	7	78	57.4
St. Louis	79	107	−22	70	37.2
Boston	71	104	−14	72	43.4
San Francisco	57	101	29	80	22.3
Oklahoma	80	108	−17	70	31.7
Charleston, S. C	81	104	7	78	52.1
Galveston	83	99	8	81	47.1
Norfolk	78	102	2	....	49.5
Colon, Panama	80	93	66	84	127.8
Balboa Heights, Canal Zone	80	97	63	83	69.4

The lines of demarcation between the dry and wet seasons are neither constant nor always clearly marked. Occasionally the dry season begins as early as the 1st of December, while in other years rainy weather continues into January. Usually the rains cease in mid-December and begin again about April 20.

During the rainy season it does not rain all the time, usually not more than one or two hours of the 24. As spread over the season, rain falls about one-twentieth of the time. This is equivalent to about 40 minutes of the daylight hours. About 20 days in each month have one-one hundredth of an inch or more of precipitation; the other 10 days have less.

The Isthmus of Panama is so located that the convectional influences are very great; cyclonic disturbances are almost unknown. The Isthmian currents, due to convection of heat, are nearly vertical, and moisture evaporated in a region exposed to these currents is largely precipitated before being carried very far. The slopes of Panama's hills and mountains also obstruct and deflect upward the prevailing winds, which tends to make a well-watered country and perennial streams. So effective is this cause in producing rainfall, it is not exceptional to find luxuriant vegetation on the windward side of a mountain range, whereas the leeward side is dry, with sparse growth. While this is not true to any considerable extent in Panama, it is a fact that the rainfall varies from the Atlantic coast with its 130 inches of annual rainfall to 70 inches on the Pacific, on the average.

Long-continued rainstorms, extending over a large area are of infrequent occurrence. Rainfall is usually in the form of showers of limited areas and is influenced by topography. Storms giving a greater precipitation than 6 inches on the Atlantic side or 4.5 inches on the Pacific are of infrequent occurrence. Exceedingly heavy falls of rain occasionally occur, however. One record from Porto Bello, 2.46 inches in five minutes, stands as a world's record.[2] In regions of steep topography such rains are followed by flashy flows in the streams that make travel in the interior very difficult and even dangerous during the wet season.

Most of Panama's streams are good water producers, but either go dry or have very small flows during the dry season. The interior roads and trails are usually in bad condition, due to lack of attention. The paucity of bridges, with the consequent necessity of fording streams, tends to accentuate unduly in the traveler's mind the inherent difficulties of travel in the interior.

Winds, especially along the Atlantic coast, show marked variations between the dry and rainy seasons. During the dry season months, fresh northerly trade winds prevail, coming from the north and northeast 90 per cent of the time, with an average velocity of about 15 miles per hour. During the wet season there is considerable wind from the south and southeast, particularly on the Atlantic side.

[1] A report prepared for the Panama Commercial Association.

[2] Cf. MO. WEATHER REV., May, 1920, 48: 274-276.